J. Phys. Ther. Sci. 36: 372–377, 2024

The Journal of Physical Therapy Science

Original Article

Analyzing muscle thickness changes in lateral abdominal muscles while exercising using virtual reality

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Abstract. [Purpose] Virtual reality (VR) rehabilitation has become popular in the medical field. VR-guided exercises (VR-ge) have demonstrated positive effects on gait and trunk control. Trunk muscle activation, particularly that of the transversus abdominis (TrA), is responsible for these improvements. However, the difference in muscle activation between VR and real space remains unclear. Therefore, this study aimed to clarify the differences in trunk muscle activation during exercise therapy performed in VR and real space. [Participants and Methods] A total of 22 healthy male volunteers were divided into two equal groups: VR-ge and Control exercise (C-e) groups. Both groups performed reaching exercises in a seated position. Ultrasound imaging was used to measure the thicknesses of the right external oblique, internal oblique, and TrA muscles, both at rest and during the reaching exercises performed in six different directions. [Results] No significant differences were observed in TrA muscle thickness changes between the groups before the intervention. However, after the intervention, the VR-ge group showed significantly greater TrA muscle thickness changes during reaching compared to that of the C-e group. [Conclusion] VR-ge increased TrA activation during reaching compared to exercising in real space.
Key words: Exercise, Biomechanical phenomena, Virtual reality

(This article was submitted Feb. 5, 2024, and was accepted Apr. 4, 2024)

INTRODUCTION

Rehabilitation using virtual reality (VR) has recently attracted attention in the medical field[1)]. The mediVR KAGURA (mediVR Inc., Osaka, Japan) is an exercise therapy in which patients perform arm-reaching exercises in a seated position against a target in VR space[2, 3)]. Its effects include the extension of continuous walking distance in older patients with disuse muscle weakness after a 2-week intervention without an increase in lower limb muscle strength[2)]. Additionally, studies have shown that it improves abnormal pelvic and trunk movements during walking after hallux valgus surgery[4)]. Thus, VR-guided exercise improves gait function, despite being performed in a sitting position[2, 4)].

Electromyography (EMG) has shown that reaching exercises performed in a seated position activate the erector spinae and abdominal muscles[5)]. Furthermore, stability during walking relies on the coordinated activation of the trunk muscles[6)], and there is a positive correlation between trunk muscle thickness and walking speed[7, 8)]. The transversus abdominis (TrA) is a lateral abdominal muscle that plays a vital role in trunk control[9)]. These findings suggest that activation of the trunk muscles,

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especially the TrA, is involved in improving walking function through the VR-guided exercise[2]. However, the differences in muscle activation between reaching movements in real space and those performed in VR conditions have not yet been clarified.

Surface EMG is not suitable for evaluating the trunk muscles, which are composed of multiple layers. Instead, magnetic resonance imaging[10], computed tomography[11], and ultrasound (US) imaging systems[12] are used. Among these, the simplicity of US is useful during motion[13]. Muscle thickness changes at rest and during contraction, as assessed using US, can reflect muscle activity[14, 15]. Therefore, observing muscle thickness changes in the lateral abdominal muscles during reaching movements in VR and in real space may help to clarify the mechanism of treatment efficacy of VR-guided exercise.

This study aimed to compare the changes in the thickness of the lateral abdominal muscles before and after reaching exercises performed in VR and those performed in real space.

PARTICIPANTS AND METHODS

Twenty-two healthy male volunteers were included in this study. The inclusion criteria were no history of back pain, injury, or surgery. The exclusion criteria were presence of internal diseases and difficulty in imaging the lateral abdominal muscles owing to obesity. This cross-sectional study was approved by the Research Ethics Review Subcommittee of the Academic Committee of Morinomiya University School of Medicine on July 4, 2022 (2021-137). This study was registered in the University Hospital Medical Information Network Clinical Trials Registry (UMIN-CTR ID: UMIN000048720). All study participants were informed of the experimental details and provided written informed consent to participate.

The participants were randomly and equally assigned to the VR-ge and C-e groups using the block substitution method (permutation block). Blinding was not possible because an interventionist administered the outcome measures. In the VR-ge group, mediVR KAGURA (mediVR, Inc., Osaka, Japan) was used as the intervention method. After the participants were placed in the end-sitting position, they wore a head-mounted display and grasped the controller using both hands. The reaching directions were set to six directions (forward, 45° diagonally forward, and lateral) with the left and right upper limbs, and the reaching distance was set at 90% of the maximum reaching distance. The reaching exercise comprised 150 "horizontal games" (25 times in each direction) for a duration of 20 min (speed, 1 cm/s; outer edge of the circle, 20 cm radius from the center; inner edge of the circle, 10 cm radius from the center; controller's sensing range, 2.0 cm radius). The therapist set the direction of the target emergence to avoid movements requiring a 180° neck rotation, such as lateral to contralateral rotation. Figure 1 depicts the VR image and reaching scene. In the C-e group, the participants were placed in an end-sitting position and grasped the controller with both hands, but did not wear the head-mounted display. Similar to the VR condition, the reaching direction was set to six directions, with a maximum reaching distance of 90%. The reaching motion was performed against the targets described previously (circle: outer edge of the circle [circular ring], 20 cm radius from the center; inner edge of the circle, 10 cm radius from the center).

The outcome measures included measurements of the right external oblique (EO), internal oblique (IO), and TrA muscles, taken using an US imaging system. The transducer was positioned on the anterolateral aspect of the abdomen, midway between the iliac crest and lower edge of the thorax, with short-axis scanning. The medial end of the transducer was placed approximately 10 cm away from the midline (Fig. 2)[16]. The seven measurement conditions were a resting sitting position and a posture in which the patient reached the target point in six directions with the right and left upper extremities (resting, ipsilateral forward, ipsilateral diagonally forward, ipsilateral lateral, contralateral forward, contralateral diagonally forward, contralateral lateral [Fig. 3]). The outcome was defined as the difference in muscle thickness changes in the EO, IO, and TrA during reaching from rest to each of the six directions.

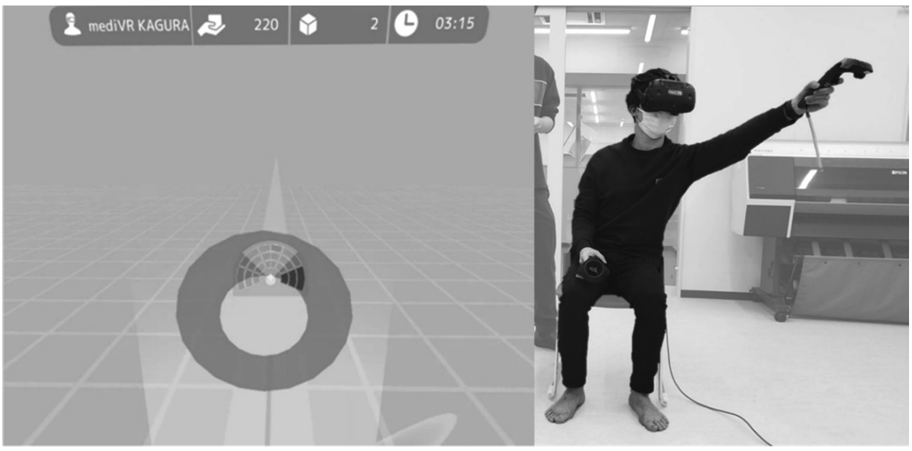

Fig. 1. Virtual reality image and actual exercise scene during the implementation of the exercise using mediVR KAGURA.

A preliminary study was conducted beforehand[17], and G*power software (version 3.1.9.7; Franz Faul, University of Kiel, Kiel, Germany) was used to calculate the sample size. This calculation estimated that 11 individuals were required in each group to identify significant differences between the groups. Repeated-measures two-way analysis of variance was used to assess the influence of the two factors, group (VR-ge and C-e groups) and timing (pre- and post-intervention), on the amount of muscle thickness change at each reach. Significant interactions were assessed, and if a main effect was found, a paired t-test was performed for the time period, and an uncorrelated t-test was performed for the group. The significance level was set at 5%. Jeffrey's Amazing Statistics Program version 0.17.2.1 (University of Amsterdam, Amsterdam, The Netherlands) was used for statistical analyses.

RESULTS

Ultimately, 22 participants were enrolled in this study and randomized to either the VR-ge (n=11) or C-e (n=11) group (Fig. 4). No significant differences in the physical characteristics were observed between the two groups. The participant information is shown in Table 1.

There was no significant difference in the change in muscle thickness of the ipsilateral TrA muscle between the groups before the intervention (forward [VR-ge, 0.3 ± 1.1 mm; C-e, 0.2 ± 1.0 mm], diagonally forward [VR-ge, 0.3 ± 1.3 mm; C-e, 0.7 ± 1.2 mm], lateral [VR-ge, 0.0 ± 1.3 mm; C-e, 0.4 ± 1.2 mm]). After the intervention, significant differences in the muscle thickness change were observed in the VR-ge group (forward [VR-ge, 1.6 ± 2.0 mm; C-e, 0.0 ± 0.7 mm]; diagonally forward

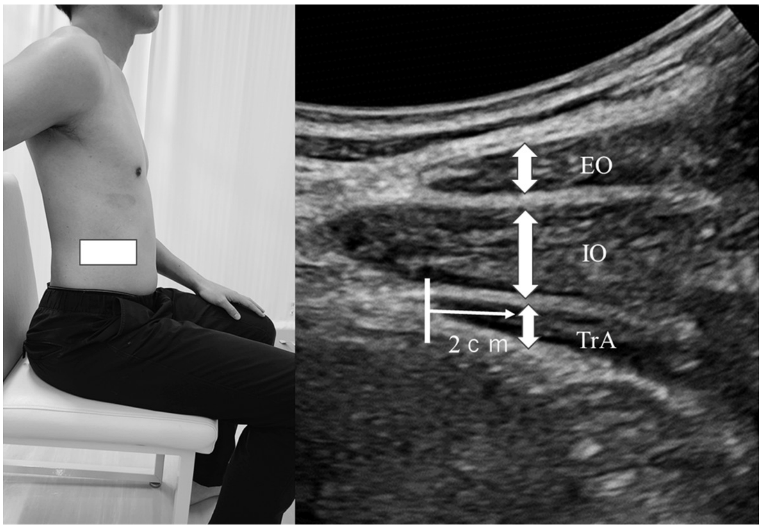

Fig. 2. Ultrasound image of the lateral abdominal muscles and the site of measurement.
TrA: transverse abdominal muscle; IO: internal oblique; EO: external oblique.

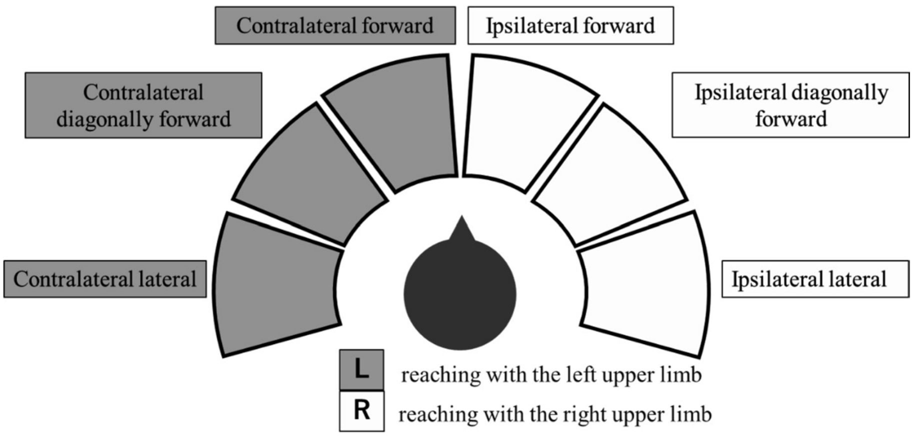

Fig. 3. Each reaching direction in the intervention.

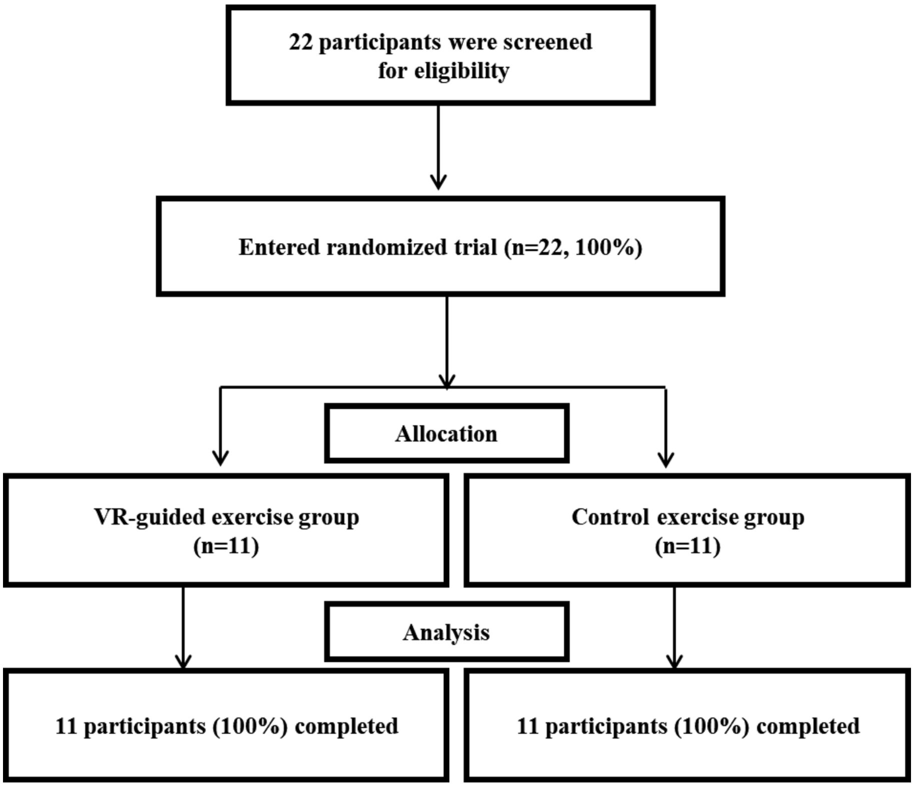

Fig. 4. Disposition of participants in the study.

Table 1. Baseline demographics of the study participants

	VR-ge	C-e
Age (years)	20.9 ± 1.8	21.4 ± 2.8
Height (cm)	170.7 ± 4.5	169.6 ± 4.8
Body weight (kg)	57.5 ± 5.4	62.0 ± 5.8

*Significant difference p<0.05 by unpaired t-test.
VR-ge: virtual reality (VR)-guided exercise group; C-e: control exercise group.

[VR-ge, 1.9 ± 1.6 mm; C-e, 0.2 ± 0.6 mm]; lateral [VR-ge, 1.6 ± 1.5 mm; C-e, 0.2 ± 0.7 mm]). Nonetheless, there was only a significant group-by-time interaction in the TrA during the ipsilateral reach. The results of the two-way analysis of variance are shown in Table 2. The changes in muscle thickness of the IO and EO did not differ significantly between the groups either before or after the intervention.

DISCUSSION

In this study, we hypothesized that the change in the thickness of the TrA muscle would be greater during reaching movements performed under VR conditions. As expected, the results of this study showed significant differences in TrA muscle thickness changes during ipsilateral anterior, oblique, and lateral reaching movements in the VR space compared with reaching movements performed in real space. This is the first study to demonstrate that the muscle activity during postural control in VR environments may differ from that in real space.

A previous study showed the abdominal muscles, as well as the erector spinae muscles, were activated during seated reaching[5]. ShahAli et al.[18] have measured muscle thickness using an US system and EMG activity in the TrA, IO, and EO during bracing and hollowing, and reported a positive correlation between the rate of change in muscle thickness and EMG activity. Dieterich et al.[14, 15] also reported that changes in muscle thickness reflected trunk muscle activity during resting and isotonic contractions using an US device. This study found that the TrA was more active in the transversus abdominis muscle during seated reaching under VR conditions compared to real space conditions.

Table 2. Changes in muscle thickness of the lateral abdominal muscles before and after the start of the intervention

		VR-ge		C-e		
		Pre	Post	Pre	Post	
Ipsilateral (mm)						
Forward	EO	0.9 ± 3.4	−0.2 ± 2.5	0.5 ± 1.0	0.2 ± 2.8	
	IO	1.2 ± 3.9	1.7 ± 2.8	2.4 ± 3.7	1.8 ± 1.1	
	TrA	0.3 ± 1.1	1.6 ± 1.5	0.2 ± 1.0	0.0 ± 0.7	*#†
Diagonally forward	EO	1.6 ± 3.0	0.8 ± 3.6	0.7 ± 1.6	−0.4 ± 0.9	
	IO	1.8 ± 5.3	4.2 ± 5.3	2.6 ± 3.6	2.8 ± 1.9	
	TrA	0.3 ± 1.3	1.9 ± 1.6	0.7 ± 1.2	0.2 ± 0.6	†
Lateral	EO	1.2 ± 3.3	0.2 ± 3.1	1.5 ± 3.3	−0.7 ± 2.4	#
	IO	1.9 ± 5.7	5.0 ± 5.0	3.3 ± 5.5	2.8 ± 2.6	
	TrA	0.0 ± 1.3	1.6 ± 1.5	0.4 ± 1.2	0.2 ± 0.7	#†
Contralateral (mm)						
Forward	EO	0.5 ± 1.9	1.0 ± 2.6	0.8 ± 2.6	1.2 ± 3.7	
	IO	1.8 ± 1.7	1.4 ± 4.3	2.9 ± 2.5	3.2 ± 2.5	
	TrA	0.4 ± 1.4	1.7 ± 2.0	0.2 ± 0.8	0.5 ± 0.7	#
Diagonally forward	EO	0.1 ± 2.5	−0.3 ± 2.8	0.0 ± 1.6	−0.1 ± 0.8	
	IO	−0.5 ± 2.8	0.4 ± 4.2	0.4 ± 2.1	1.8 ± 1.8	
	TrA	0.1 ± 1.6	1.0 ± 2.4	−0.6 ± 1.0	−0.1 ± 0.9	
Lateral	EO	0.2 ± 1.8	0.2 ± 1.9	0.3 ± 2.0	0.7 ± 1.7	#
	IO	−0.7 ± 2.4	0.1 ± 3.8	1.0 ± 3.1	2.4 ± 3.4	
	TrA	−0.1 ± 1.0	0.4 ± 1.6	0.2 ± 0.8	0.1 ± 0.7	

Values are represented as mean ± SD. *#†indicates test results by repeated-measures 2-way ANOVA, *Group: Significant difference p<0.05, #Timing: Significant difference p<0.05, †Interactions: Significant difference p<0.05.
VR-ge: virtual reality (VR)-guided exercise group; C-e: control exercise group; TrA: transverse abdominal muscle; IO: internal oblique; EO: external oblique; SD: standard deviation.

Previous studies have reported that VR rehabilitation exercise results in a significantly lower center of pressure compared to that resulting from conventional balance exercise in healthy participants[19], and that VR is more effective than vestibular rehabilitation alone in improving vestibular function in vestibular dysfunction[20]. However, no study has yet measured the activity of the lateral abdominal muscles during VR exercise. Therefore, this study presents novel results that VR-guided reaching in a seated position increased TrA activation.

The TrA is one of the deep abdominal muscles involved in trunk control[18] and is thought to play a role in the segmental control of the lumbosacral spine during exercise. It also plays an important role in anticipatory postural adjustment (APA)[21]. The feed-forward muscle activity patterns associated with APA are planned and coordinated by the central nervous system, resulting in involuntary TrA contractions that contribute to trunk stability during early physical activity[22]. The TrA is also involved in the control of the lumbosacral spine. During normal reaching exercises, target points and body positional information are provided through visual and proprioceptive feedback[23]. However, during reaching exercise performed in VR space, it is not possible to visually perceive one's own body, which may have resulted in the training of postural control based on prediction.

This study has several limitations. First, the study participants were all healthy adults, and the results may differ for older participants or those with central nervous system diseases. Further, the present study only confirmed the effects on the thickness of the TrA muscle during treatment and did not investigate the effects on the performance of actual postural control tasks; thus, further studies are required. Second, kinematic changes during the VR exercise therapy were not investigated, including the muscle activity output of the TrA, which varies with the anterior-posterior pelvic tilt[24]. It is possible that the kinematic changes in the trunk and pelvis are higher in the VR group compared with those in the normal reaching group, and these kinematic changes need to be clarified in future studies. Finally, because the present study required imaging of the lateral abdomen during reaching, the therapist and evaluator could not be blinded to the treatment groups, which might have induced bias. However, because there was no change in the muscle thicknesses of the IO and EO, the inability to fully implement blinding had little effect on the results.

The results of this study showed significant differences in TrA muscle thickness changes during ipsilateral anterior, oblique, and lateral reaching movements performed in the VR space compared to those performed in real space. This suggests that VR-guided exercise may activate the TrA during reaching movements.

Funding

This work was funded by JSPS KAKENHI Grant Number JP21K17503.

Conflicts of interest

Masahiko Hara is a director of mediVR Inc., in which he holds private equity. Masashi Kitano is full-time employee of mediVR Inc.

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